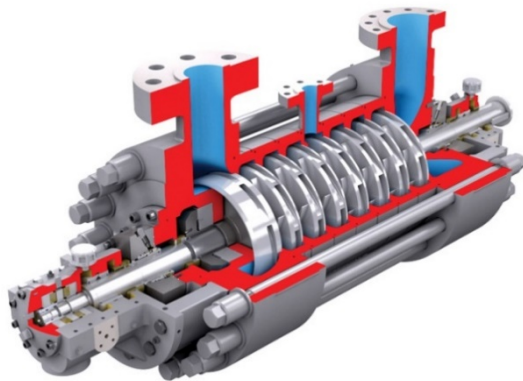


# MEGAPROJECT - LESSONS LEARNED

- **Chris Gilmour, P.Eng.,**  
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# Presenters

## **Chris Gilmour, P.Eng.**

Chris Gilmour is a consulting Machinery Engineer based in Calgary, Alberta. He has over 30 years of experience, most recently 7+ years as the Chief Machinery Engineer at Northwest Redwater Partnership on Phase 1 of the Sturgeon Refinery project which started operation in November 2017. Chris has also worked for Shell Canada, Fluor Canada, and NOVA Gas Transmission. Chris graduated in 1985 with a B.Sc. (Honours) in Mechanical Engineering from Queen's University

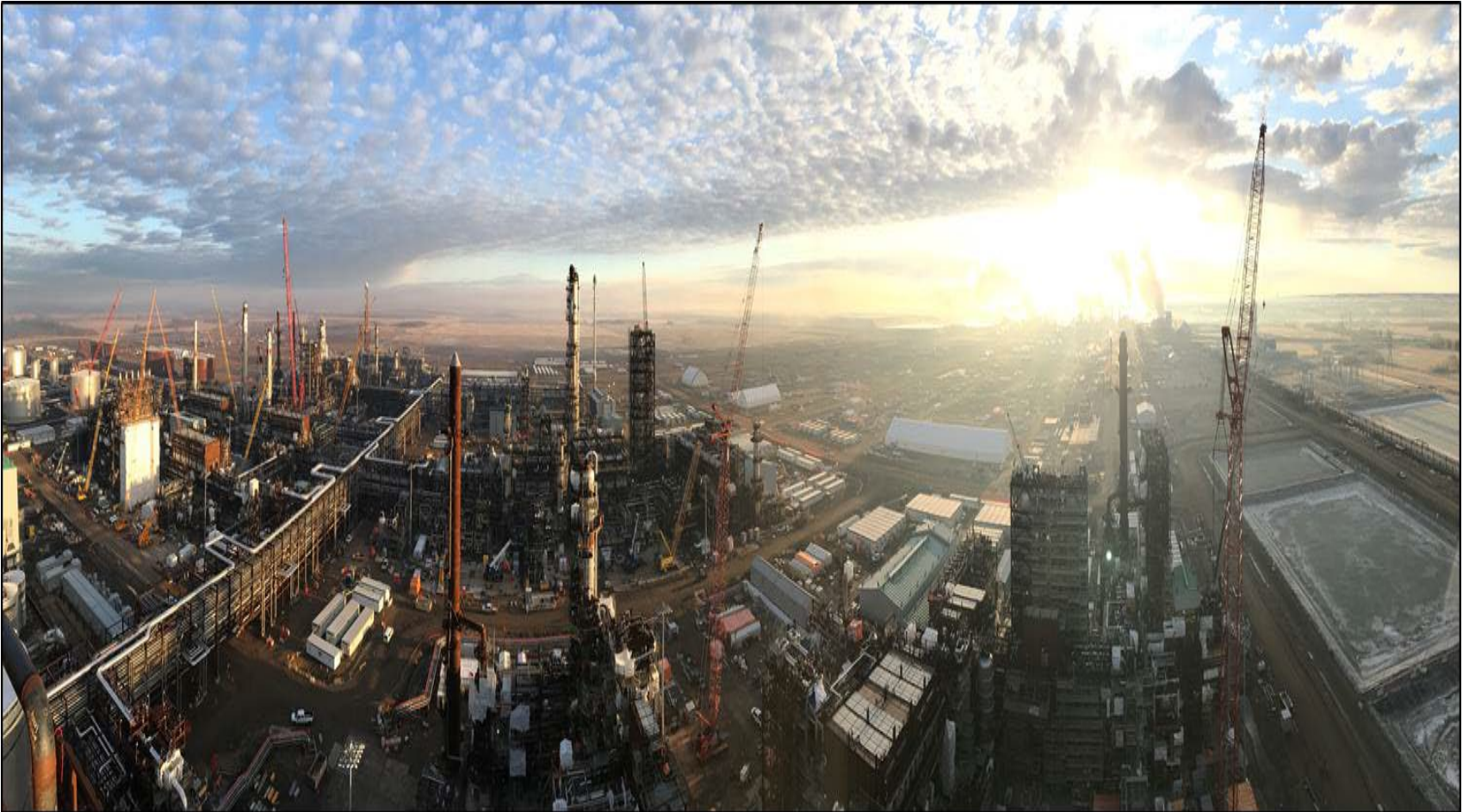


## CALGARY PUMP SYMPOSIUM

[www.calgarypumpsymposium.ca](http://www.calgarypumpsymposium.ca)

September 26-27, 2019

# Project Overview



# Project Overview

- New (green-field) refinery outside Edmonton
- 50,000 bpsd processing bitumen --> diesel
- Process Units: Crude, LC Finer, Hydro-Processing, Gasification, Light Ends Recovery, Sulphur Recovery Unit, Utilities, Tank Farm
- Engineering done primarily in Calgary, Frankfurt, Madrid, Toronto
- Began processing sweet crude -> diesel in late 2017, switched to sour crude -> diesel in 2018

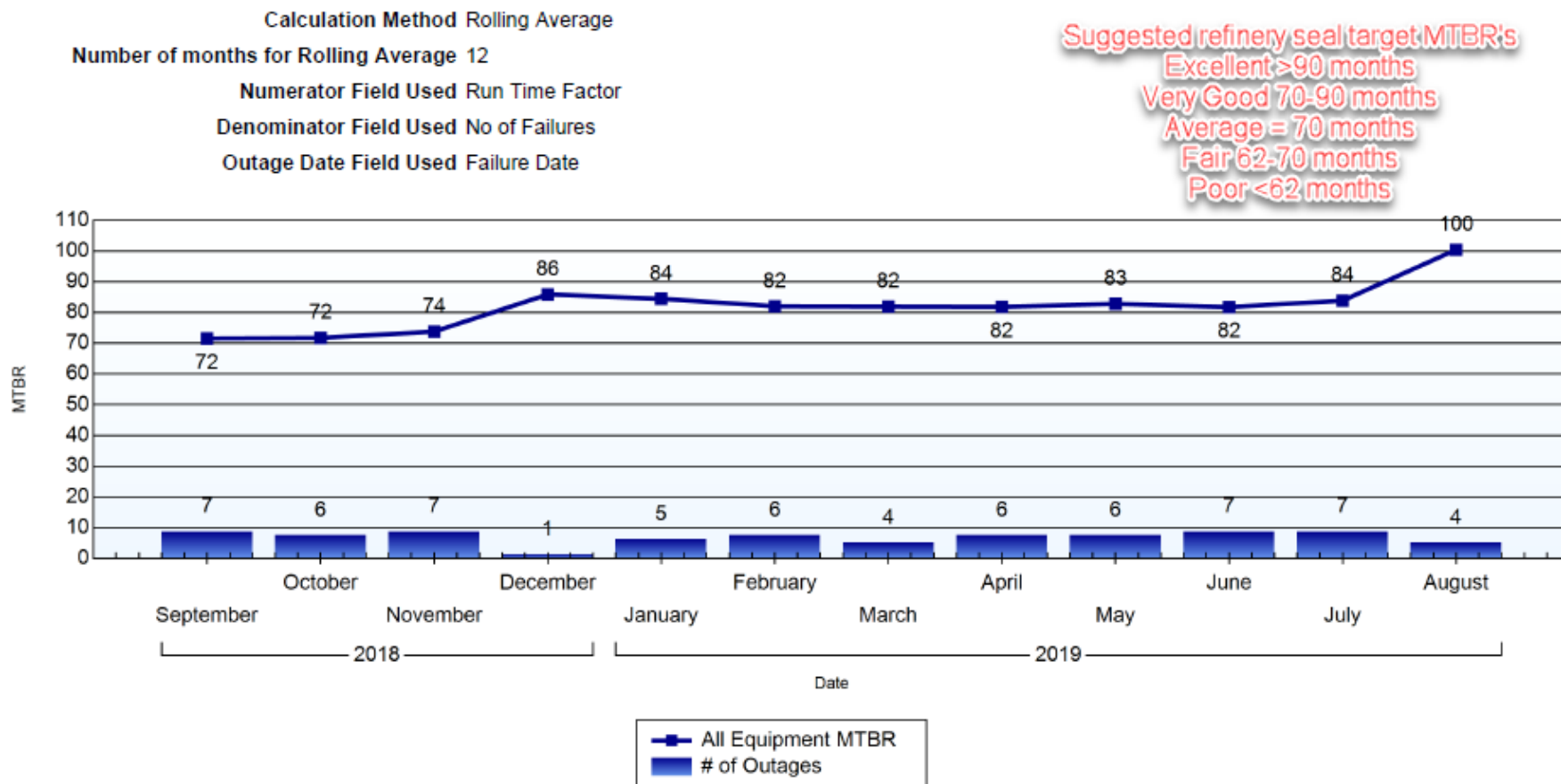


# Info on the Plant

- The following slides provide information on the plant



# MTBR – last 12 months



# Pump Overview – API 610 pumps

| Type        | # services / pumps | Largest HP | Supplier(s) (# pumps)                     |
|-------------|--------------------|------------|-------------------------------------------|
| BB5 - large | 5 / 9              | 2550       | SOC1 (9 + 2 spare bare pumps)             |
| BB5 - small | 1 / 2              | 200        | Supplier1 (2)                             |
| BB3 - large | 2 / 4              | 1475       | SOC1 (4)                                  |
| BB3 - small | 1 / 3              | 1750       | SOC2-1 (3)                                |
| BB2         | 20 / 36            | 3000       | SOC2-1 (32), Supplier1 (4)                |
| OH2         | 41 / 80            | 800        | SOC2-1 (67), Supplier1 (12), SOC2-2 (1)   |
| OH3         | 82 / 149           | 200        | SOC2-1 (110), Supplier1 (29), SOC2-2 (10) |
| OH6         | 1 / 2              | 40         | Supplier2 (2)                             |





# Pump Overview – other centr pumps

| Type               | # services / pumps | Largest HP | Supplier(s) (# pumps)                    |
|--------------------|--------------------|------------|------------------------------------------|
| BB1                | 1 / 2              | 900        | SOC2-2 (2)                               |
| BB4                | 2 / 4              | 600        | Supplier3 (2), SOC2-2 (2)                |
| Surface Production | 2 / 4              | 300        | Supplier4 (4)                            |
| ANSI B73           | 20 / 44            | 150        | SOC2-2 (44)                              |
| Mag Drive          | 4 / 5              | 20         | Supplier5 (2), Supplier6 (2), SOC2-2 (1) |
| VS4 sump pumps     | 13 / 14            | 50         | SOC2-2 (7), Supplier1 (7)                |
| VS1 water pumps    | 7 / 13             | 1600       | SOC2-2 (8), Supplier7 (5)                |
| Submersible        | 5 / 8              | 25         | SOC2-2 (8)                               |





# Pump Overview – PD pumps

| Type              | # services / pumps | Largest HP | Supplier(s) (# pumps)            |
|-------------------|--------------------|------------|----------------------------------|
| API 674 Recip PD  | 2 / 5              | 400        | PDSupplier1 (2), PDSupplier2 (3) |
|                   |                    |            |                                  |
| Chemical Inj Pkgs | 54 / 116           | 15         | SOC2-3 (106), PDSupplier3 (10)   |
| Diaphragm PD      | 4 / 10             | 15         | PDSupplier4 (10)                 |
| Rotary PD         | 9 / 18             | 40         | PDSupplier5 (18)                 |



# Sealing Overview

| Type   | Sub-type           | # services / pumps | Seal Auxiliary Supplier (#'s reflect # of seals)     |
|--------|--------------------|--------------------|------------------------------------------------------|
| Dual   |                    | 125 / 218          |                                                      |
|        | 53b (no circ pump) | 24 / 46            | Supplier2 (7), Supplier1 (45)                        |
|        | 53b (w/ circ pump) | 30 / 52            | Supplier2 (54), Supplier1 (10)                       |
|        | 54 (unit-wide)     | 37 / 72            | Supplier3 (3x consoles), Supplier2 (82x seal panels) |
|        | 74                 | 20 / 34            | Supplier2 (21), Supplier1 (13)                       |
|        | 52                 | 6 / 12             | Supplier2 (10), Supplier1 (6)                        |
|        | 54 (stand-alone)   | 5 / 9              | Supplier1 (9x consoles)                              |
|        | 32 / 54            | 1 / 2              | Supplier2 (2)                                        |
|        | w/ Plan 32         | 11 / 22            | Owner                                                |
| Single |                    | 62 / 124           | n/a                                                  |
|        | w/ Plan 32         | 5 / 9              | Owner                                                |



# Instrumentation

- The following pumps were instrumented

| Equipment                        | Qty | Items            | Instrumentation                                                                    |
|----------------------------------|-----|------------------|------------------------------------------------------------------------------------|
| BB5 pumps (except the 200hp one) | 9   | Pump+gear+driver | Prox probes, keyphasors, brg RTD's                                                 |
| BB3 pumps                        | 7   | Pump+driver      | Prox probes, keyphasor, brg RTD's                                                  |
| Surface Production               | 4   | Pump             | Vibration Tx                                                                       |
| BB2 pumps >1000hp                | 8   | Pump+driver      | Prox probes, keyphasor, brg RTD's                                                  |
| VS1 CW Circ (1600hp)             | 3   | Pump+driver      | Velocity probes                                                                    |
| API 674 Recip PD                 | 5   | Pump+gear        | Velocity probes, accelerometers, brg RTD's; 1 service monitored by PROGNOST system |



# Vibration Program

- The plant has the GE-BN System 1 monitoring critical centrifugal pumps and compressors
- The plant purchased three CSI 2140 analyzers and the corresponding software, in order to implement a periodic vibration monitoring program that generally follows (for the pumps):
  - Monthly for critical and essential pumps and drivers
  - 3-monthly for less critical pumps and drivers
  - None for non-critical pumps and drivers



# Lubrication

- 28 of the pumps in this plant had lube oil systems (all large BB5's, all BB3's, all Recip PD's, 2@ BB2's)
- Closed-loop oil mist systems were used in all Units and in the Tank Farm (except for remote pumps)
- Owner supplied all lubricants, including first fills
  - Allowed us to consolidate/rationalize across the plant
  - Supply of all oils and greases were bid and awarded to one supplier
  - Further rationalization after contract awarded
- The typical lubricant is an ISO VG-46



# Lubrication Sampling

- Lube sampling is done by site personnel with analysis by a lube lab in Edmonton and generally follows this guideline:
  - Monthly sampling for oil systems with a steam turbine
  - 3-monthly sampling for oil systems with no steam turbine
  - Bi-annual change-out with no sampling for small bearing housings



# Heat Tracing and Insulation

- On this project a 3<sup>rd</sup>-party did the heat tracing design and supplied materials, and they depended on the EPC's for information on what needed to be HT&I'd
  - The Process group identified which pumps required HT&I, but not the auxiliaries
- It seemed to me that better guidelines from the Owner would have simplified and streamlined this effort, so we wrote some for a future project phase:
  - inside heated buildings, HT&I is not required
  - Outside, HT&I is required for: oil systems; Plan 54 seal systems (except the tubing between the panel and seal on unit-wide systems); seal auxiliaries for single seals when the process pump is HT&I'd; seal auxiliaries for Plan 52, Plan 53a, Plan 53b





# Construction

- The Owners team during the construction of this project consisted of 2 machinery engineers and 2 millwright inspectors (there was also the plant millwright team, but they were busy getting prepared for the plant to start-up: setting up shops and warehouse, buying tools, writing procedures, etc); it was barely enough, and only because the unit schedules were not coincident
- There were 6 different Unit/contractor teams to deal with, each with a different approach, and different degrees of cooperation



# Construction

- Can't stress enough the importance of reviewing the proposed Inspection and Test Plans, identifying the Owner Witness/Observe/Review points, clarifying which equipment is covered, etc
- We 'Observed' these items (and made sure to be there):
  - Acceptability of base preparation prior to setting equipment
  - Pre-grout level check
  - Grout placement
  - Post-grout level check
  - Alignment of piping to equipment
  - Shaft alignment



# Pump Installations

- All pump installations met API 686 criteria for level/coplanar (pre and post grout), pipe strain, shaft alignment
  - But not without a fight



# Grouting Pumps

- Epoxy grout was used to grout all pumps
- Cementitious grout (with a top pour of epoxy grout) was used to grout auxiliary skids



# Pre-Commissioning

- Includes line cleaning (air blows, chemical cleaning, steam blows), oil flushing, rotation checks, motor runs, loop checking
- On this project this was an Owner led activity, with specialist contractors
- This approach worked well, especially the oil flushing where Owner involvement resulted in better results quicker with less effort/cost
- In most cases the flushing was done with the service oil, except the Recip PD pumps (which use a heavier oil) where we used a lighter oil from another service



# Commissioning and Start-Up

- This was an owner-led activity (per usual)
- C&SU of pumps and auxiliaries in the first unit (Utilities) revealed the need to check some things prior to start-up in subsequent units, particularly: strainers (mesh sizes, alarm settings), Q-min valves/RO's (sizes, settings), alarm/trip settings, seal system pressures and alarm settings prior to start-up of the units
- Pump and auxiliary start-ups went much more smoothly in the subsequent units



# Unique Features

- The following slides outline some unique features/approaches on the project



# Supplier of Choice Agreements

- SOC agreements were used to get the best value for money, and simplify/streamline by:
  - Agreeing to commercial terms that are balanced
  - Concentrating the business so that the relationship is significant to both parties, and worth spending time and resources supporting
  - Facilitating more open discussion on technical issues:
    - Technical specifications (ie. cost/benefit of certain technical requirements)
    - Equipment selections
  - Consistency across the project (especially in equipment configuration)
    - Which reduces the overall effort required to acquire equipment, do the installation designs, etc
  - Simplify and streamline spare parts requirements through
    - Maximizing spare parts interchangeability
    - Minimizing business interfaces
  - Simplify and streamline the ongoing technical support for operation and maintenance





# Supplier of Choice Agreements

| Equipment                                   | Supplier of Choice |
|---------------------------------------------|--------------------|
| BB5 and BB3-large pumps                     | SOC1               |
| BB3-small, BB2, OH2, OH3 pumps              | SOC2 – Vendor1     |
| ANSI B73, BB1, VS1, VS4, submersible pumps  | SOC2 – Vendor2     |
| Chemical Injection Packages, metering pumps | SOC2 – Vendor3     |
| Pump shaft seals                            | SOC3               |
| Pump couplings                              | SOC3               |
|                                             |                    |
| LV motors                                   | Motor Vendor1      |
| MV motors                                   | Motor Vendor2      |



# Sole Sourcing

- Some equipment was sole-sourced, to achieve consistency within the plant:
  - Oil Mist Systems (11x)
  - Gearboxes (16 total, 13x for pumps)
  - GP Steam Turbines (10 total, 6x for pumps)



# Pump Sealing

- Deciding which pumps required dual seals and which seal flush plans were preferred were Owner-driven activities done very early (in FEED), to achieve consistency within the plant:
  - Consistent criteria applied to decide where dual seals were required, with input from Process for each Unit; documented reasons why
  - Consistent approach to seal flush plan selections
- In my opinion this was a major reason for our very good seal life since start-up



# Testing with Shop Seals

- Pumps which had dual seals were tested with shop seals rather than job seals
  - Avoid issues with degradation of seals while running on water during test
  - More importantly, avoid issues with preservation (including freezing during outdoor storage during winter)
- In my opinion, this was a major reason for how few issues we had with seal preservation and infant mortality



# Bid the Pump Seal Auxiliaries

- Decided to competitively bid the pump seal auxiliaries after failing to align on scope / cost
- Resulted in significant cost savings over original budgetary costs
- Applied an 80/20 approach where most of them were supplied by the winning bidder, but a few here and there came from the seal supplier

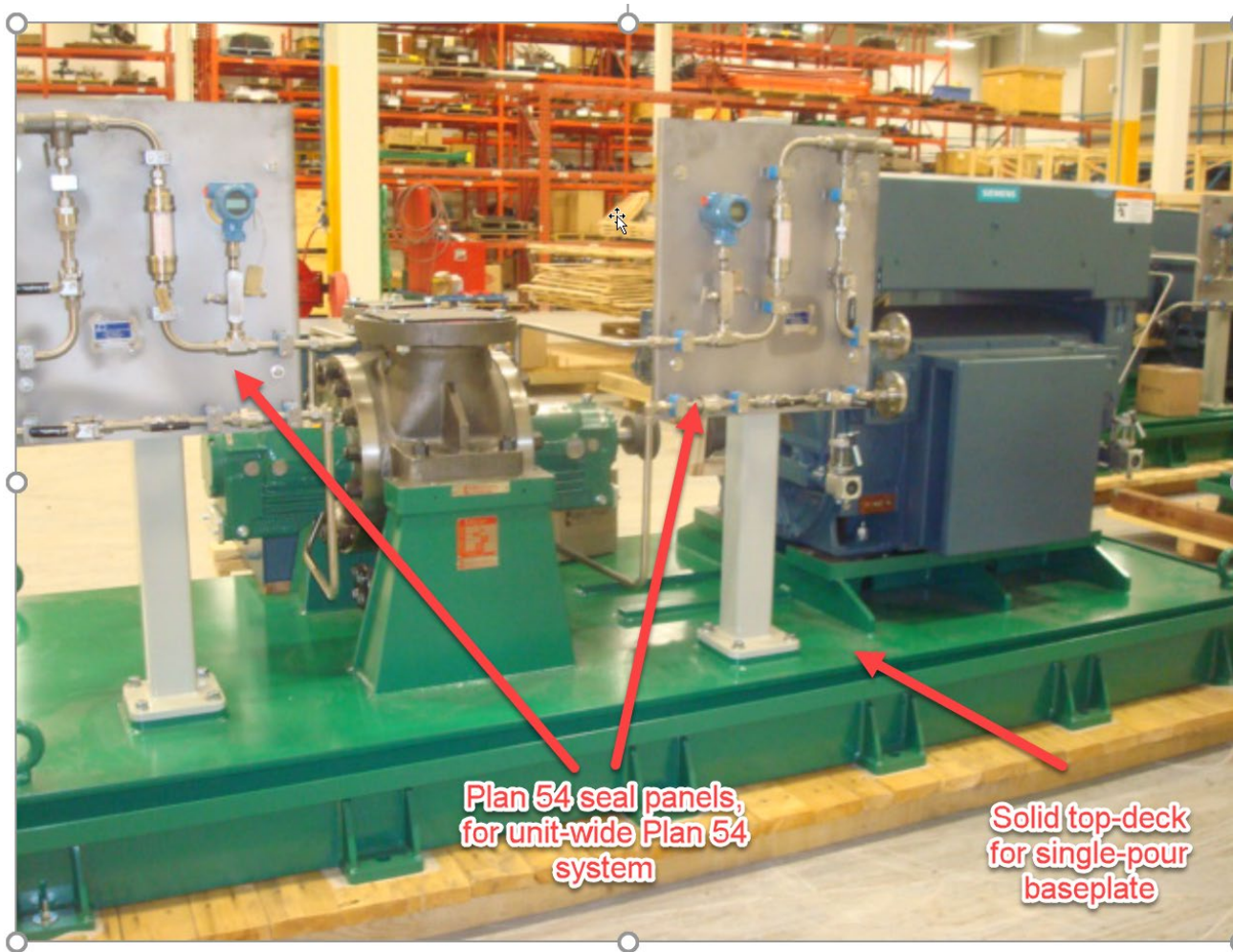


# Pump Baseplates

- Extra-stiff pump base-plates only requiring a bottom pour of grout were utilized (mostly) on this project
  - Our SOC pump supplier (SOC2-1) supplied base-plates with a solid plate top
  - We believed (and still do) that this was the cost-effective approach
  - We did not have issues installing these, or with vibration after start-up due to this approach



# Pump Baseplates



11-PU111A/B Vacuum Tower Bottoms – 300hp – final inspection at CPC Jan-2015

# Seal Systems on Pump 'Bases'

- On this project the pump seal auxiliaries were mounted on the pump baseplates, and tubed to the seal gland, by the SOC pump suppliers
  - For VIL pumps, the seal auxiliaries were mounted to the motor support stand, and tubed to the seal gland, by the SOC pump suppliers
- In my opinion this is the way to go, since we had no issues with access / routing / proximity / wrong connections (which we would have if the auxiliaries were shipped loose for field installation)

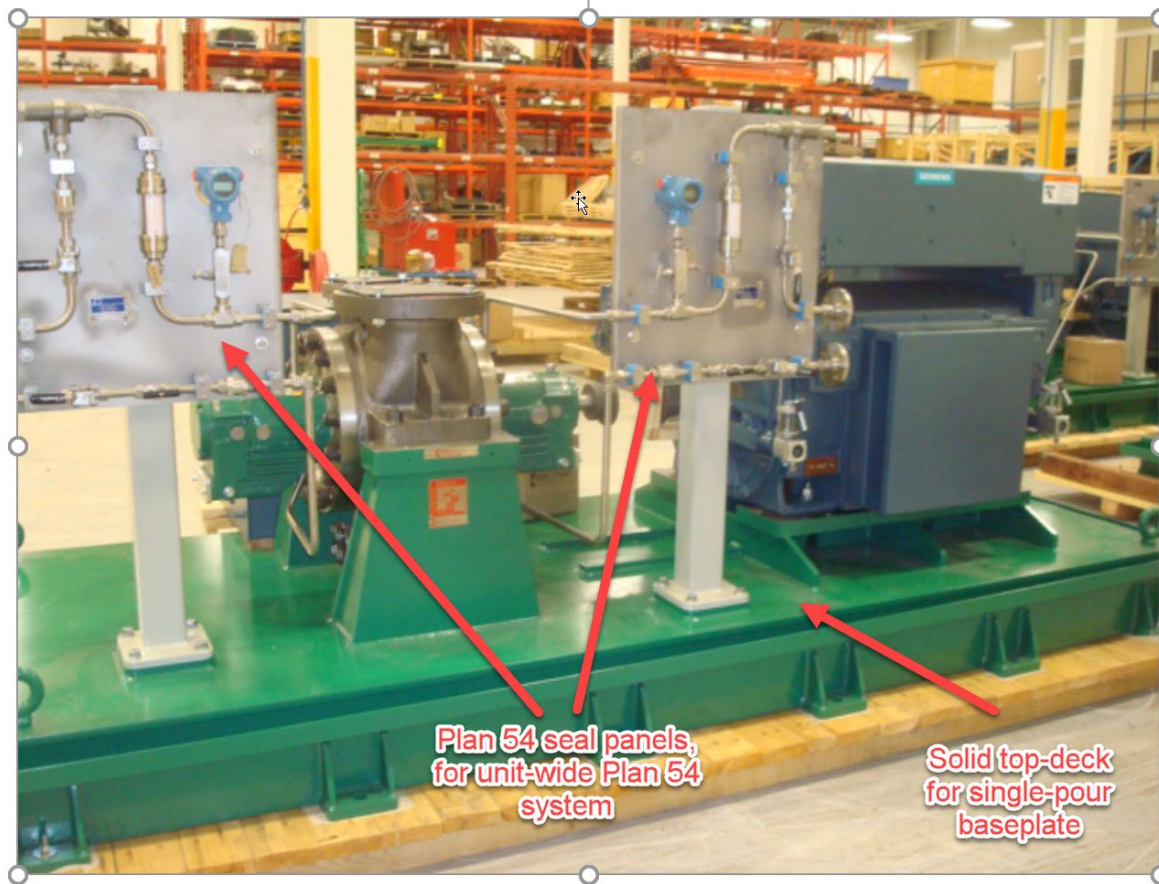




# Seal Systems on Pump 'Bases'



# Seal Systems on Pump 'Bases'



Plan 54 seal panels,  
for unit-wide Plan 54  
system

Solid top-deck  
for single-pour  
baseplate

11-PU111A/B Vacuum Tower Bottoms – 300hp – final inspection at CPC Jan-2015

# Oil Mist Systems

- Closed-loop oil mist systems were used in all Units and in the Tank Farm (except for remote pumps)
  - For improved reliability, decreased maintenance
  - 11 systems in total
  - An ISO VG46 synthetic oil is used in all these systems
- In my opinion, this is a major reason for our very good reliability since start-up



# Unit-Wide Plan 54 Seal Systems

- Unit-wide Plan 54 seal systems were applied in the Crude / LC Finer / Hydro-Processing units
- Supported about 26 seals in each unit
- Each consisted of a central console with a 9000-liter tank, 2x OH2 pumps, supply and return filters, return pressure control valve and H/X
  - Diesel is the seal fluid used in all three systems
  - The console and system piping were flushed (with diesel) to a high state of cleanliness prior to start-up
- Since start-up, the MTBR for the seals on these systems is over 140 months (including infant mortalities)

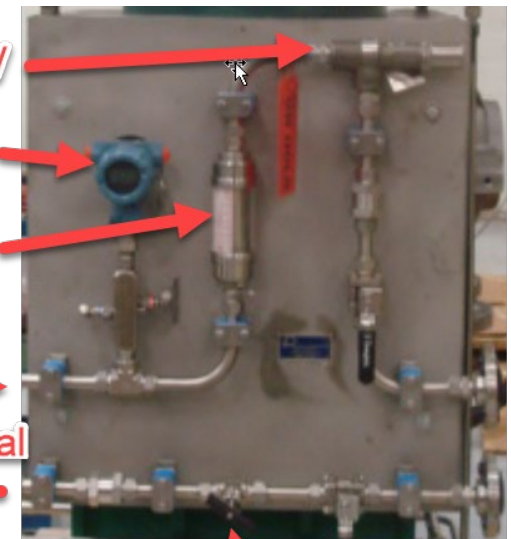




# Unit-Wide Plan 54 Seal Systems



11-PK103 – Plan 54 Console – final inspection at Lube Power in Detroit area, May-2015



A seal panel for each seal

# Surface Production Pumps

- Surface Production Pumps were used in two services that traditionally would have been Recip PD pumps, primarily to eliminate the high maintenance required by the Recip PD pumps
  - Wash Water injection: 24.5 m<sup>3</sup>/h @ 1770m Head, P-dis= 176 bar (91 stage pump, 3570 rpm, 300hp)
  - HP Purge Oil: 11 m<sup>3</sup>/h @ 2720m Head, P-dis= 230 bar (133 stage pump, 3570 rpm, 200hp)
- They have been operating well so far



# Surface Production Pumps



12-PU108A/B – HP Wash Water Pumps – 300hp, 176 bar P-disch – on test at GE Wood Group, Tulsa, OK, USA, Dec-2014

# Pump Warehouse

- This project utilized an Edmonton-area 4,500 m<sup>2</sup> warehouse (to which were added an oil mist system, some shelving) to store most of the rotating equipment
  - This warehouse was located / arranged / operated on the Owner's behalf by Westpower
  - This size seemed large at first but filled up quickly. We were lucky that the unit schedules were staggered a bit
- First pump deliveries in the fall of 2013 (4 years before plant s/u); the last deliveries to site from the warehouse were in the spring of 2016 (more than a year before startup)
  - The alternative (all that equipment sitting outside in a field at the site for 3-4 years) is not very appealing
  - Even so, the Contractors were reluctant to use the warehouse (even though the Owner was paying for it) seeming to see it as a loss of control of 'their' equipment
- The warehouse was a great success





# Pump Warehouse



# Lessons Learned

- The following slides outline some lessons learned on the project (not in any particular order)



# Documentation

- There are a lot of documents on a mega-project, and a document management system is a must-have (we had one), but assigning 'meta-data' to all the documents is not a fool-proof process, and it's the only way to find documents
  - It would have been helpful to categorize the documents into 'owner' / 'engineering' / 'vendor' to differentiate who originated it, and to further categorize the 'vendor' docs by Purchase Order #
- Just the rotating equipment documents are a huge number of documents
- Receiving a CD from the Supplier with the manuals and all the documents for the order was very helpful
- Few suppliers had done a top-notch job of ensuring that necessary technical information from sub-suppliers was complete (eg. Was the datasheet for the oil pump and oil cooler included?)



# Lube Oil Systems

- We had a few issues with pump oil systems (and often struggled to find the information on the sizing basis in the supplied documentation)
  - Supply orifice sizes too large and bearings flooding (we ended up resizing these ourselves)
  - Control of indirect immersion heaters (we changed to a heat transfer fluid in the tube, and changed the control logic and setpoints)
  - Control valve sizing (we changed valve trims, but really it needs a smaller valve)
  - Return-flow restricted by sight-flow-indicators with paddle-wheels (we removed the paddle-wheels)
- Afterwards we revised our Oil System specification to give more explicit direction to avoid those issues



# Pump Bearings

- 4 of the BB2 services had sleeve bearings, 1 of these had a pressure lube system, the other 3 were purge-mist lubricated from the unit oil mist system
- We had an issue with 1 of the purge-mist lubricated services:
  - the product is very hot (350C) and the oil in the bearing housings gets too hot
  - We should have added bearing cooling coils to this service, and are in the process of doing so

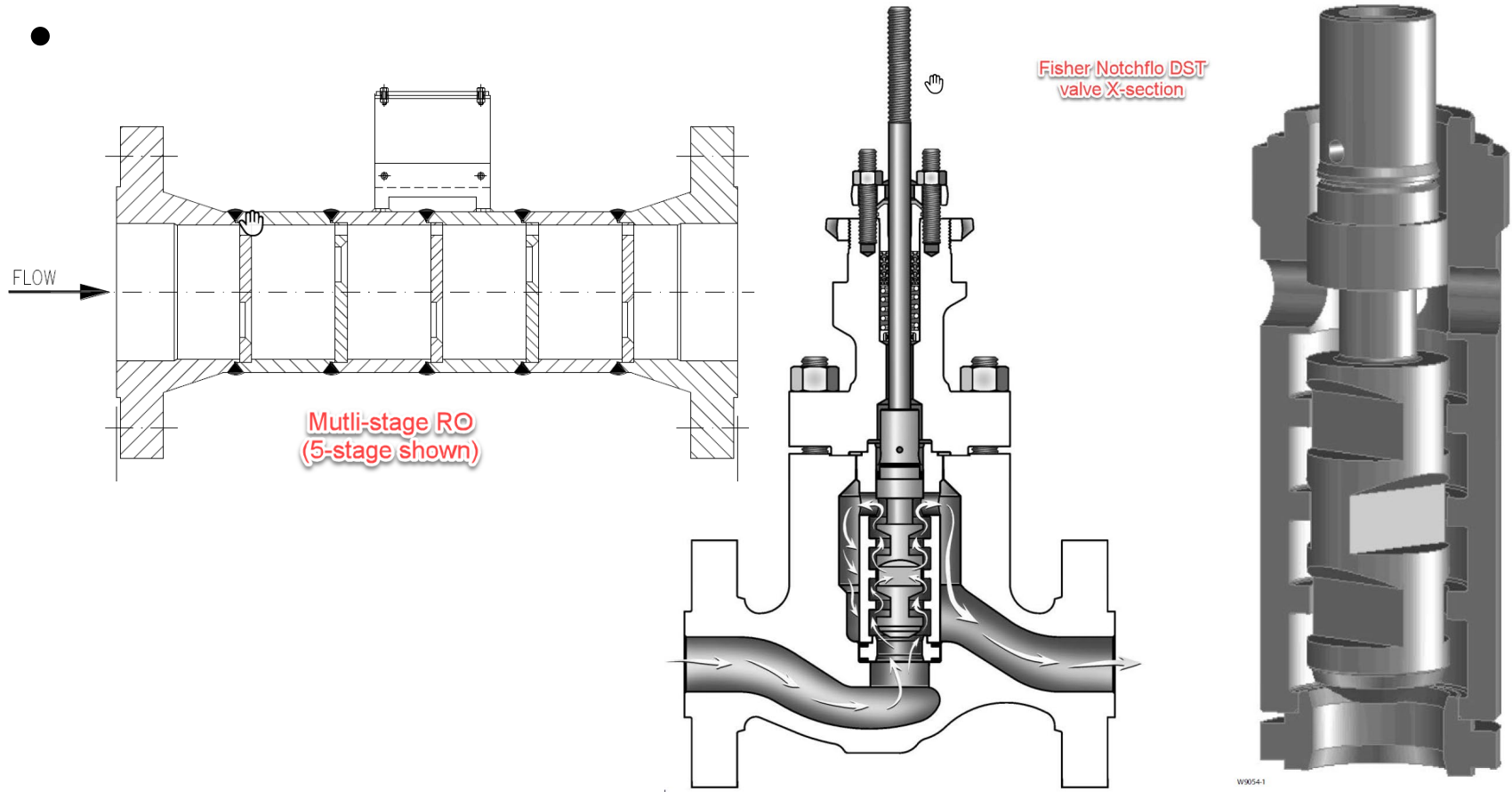


# Pump Warm-up Lines

- Some of the pumps require a warm-up line
  - This is typically a 1" or 2" line with a gate valve and a restriction orifice (RO) around the discharge check valve
  - Typical warm-up flow is 3% of Q-rated, with minimum RO diameter of 1/8"
  - Some of these are especially large and hot and require a special warm-up arrangement
    - For these we piped the warm-up both to the discharge of the pump and to the pump drain line(s)
  - In some cases there is cavitation across the warm-up RO leading to vibration and/or erosion
    - For these we prefer either a multi-stage RO, or an anti-cavitation valve like the Fisher NotchFlo DST
    - The contractors missed identifying most of these; we are having to address the worst cases at site ourselves



# Pump Warm-up Lines



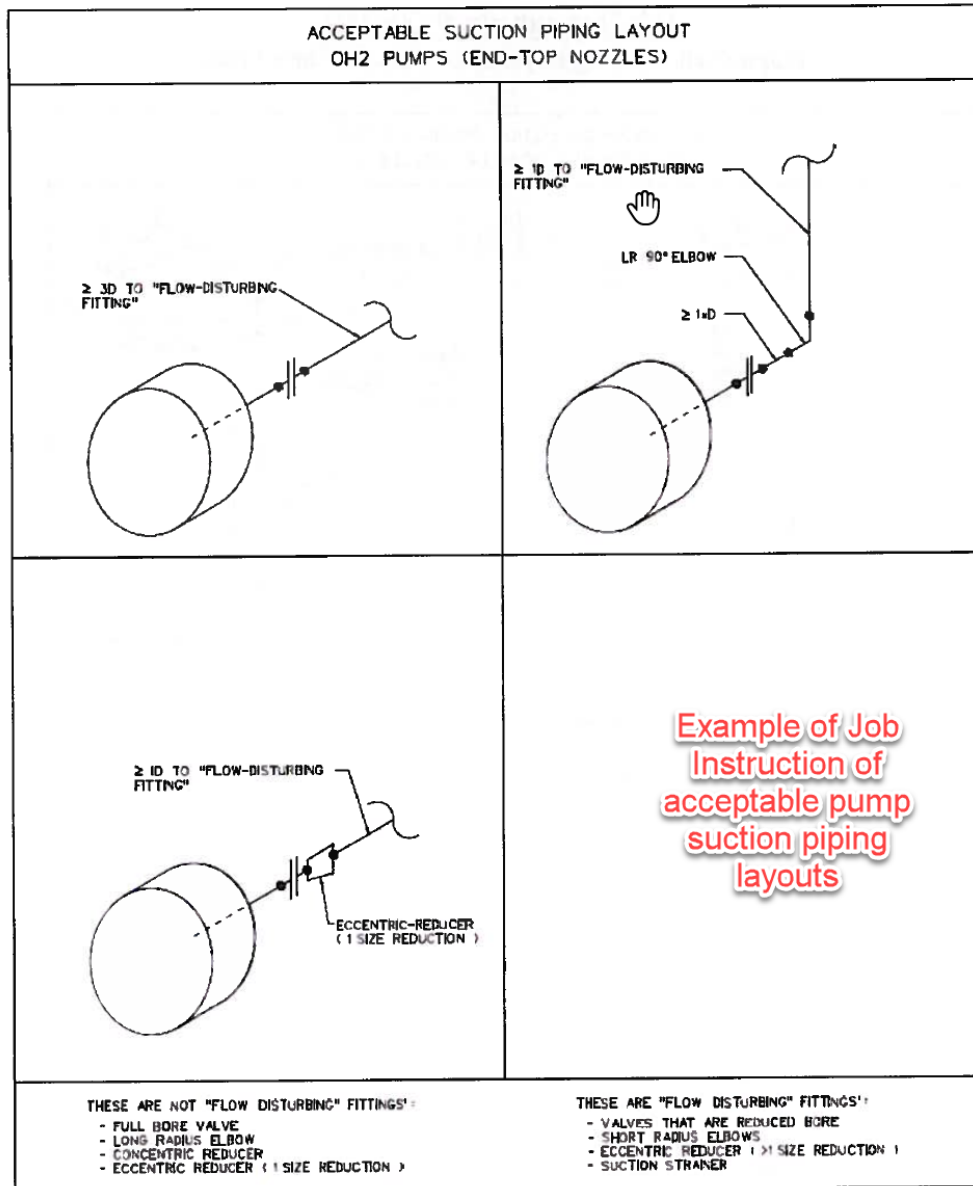
# Pump Suction Piping

- A uniform non-swirling flow profile into the pump is required
- We defined acceptable pump suction piping arrangements
- We don't have any problems with the flow profile into the pumps





# Pump Suction Piping



# Minimum Flow (Q-min) Systems

- Some services required a Q-min system
  - In most cases one system per service; in some critical services, one system per pump
  - 109 services in this plant had Q-min systems (89 with a control valve(s), 29 with a RO)
  - We defined acceptable arrangements as being a flow-element and control valve, with an option to use a restriction orifice for services with drivers less than 25hp (balancing 1<sup>st</sup> cost with op cost); ARC valves were not acceptable
    - But we ended up with 12x RO arrangements on services above this (up to 250hp), which is wasting a lot of energy



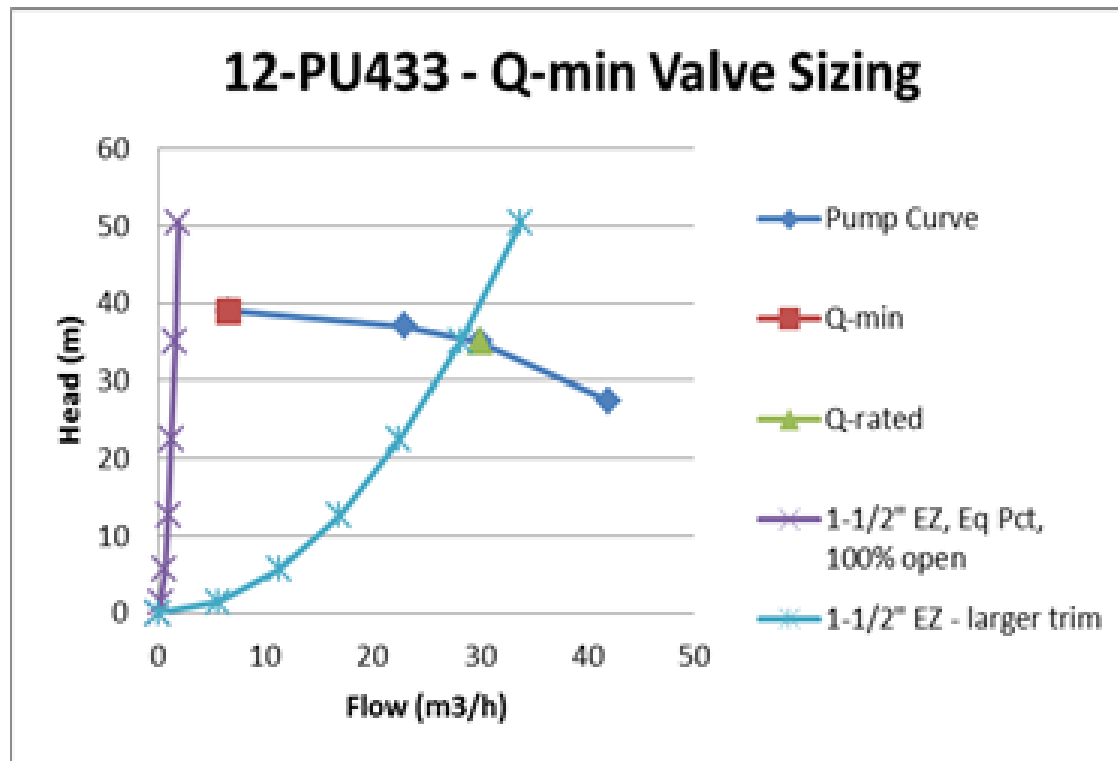
# Minimum Flow (Q-min) Systems

- We audited these systems prior to start-up and found some errors:
  - Valve and RO sizes too small, too large
  - Issues with cavitation
  - Incorrect set-points
  - Anti-cavitation valve trims (that cannot be cleaned if they get plugged) with no spare valve trim available (and some of which plugged during start-up, in spite of the line air blows)
    - In the future I would plan to start with a regular valve trim and change to an anti-cavitation valve trim when the lines were clean (ie. After a week of operating)



# Minimum Flow (Q-min) Systems

- Here's an example: the purple line is the supplied valve (too small); light-blue line is the revised valve (trim changed)



# Suction Strainers

- Our requirements were:
  - Tee-type strainers with 4 mesh
  - A few services had twin basket strainers
  - A few critical services had motorized self-cleaning filters
- Those are reasonable requirements
- EPC's seem to think it saves money to install a cone strainer instead of a tee-type, forgetting the additional labour to remove the cone and redo the pipe strains...it doesn't, put in the tee-type



# Suction Strainers

- We had issues in the first unit we started (Utilities) with strainers plugging, so we audited other units and found:
  - Tee-type strainers with up to 60 mesh, usually overtop of a perforated plate with  $\frac{1}{4}$ " holes (all these fine meshes were removed)
  - Basket strainers with unrealistically fine mesh (up to 500 mesh), holes that are too small ( $< \frac{1}{4}$ " ) (fine meshes were cut off, and some new baskets with larger holes were ordered)
  - Where instruments were provided, non-sensical instrument ranges and dP alarm settings (instruments were re-ranged, and more sensible settings implemented)
  - Temporary conical strainers had been installed rather than Tee-type strainers, but no plan had been made to remove them after an initial operating period (plans were made to remove them)



# Preservation of Equipment

- Preserving equipment delivered to module yards proved to be a challenge
  - There usually aren't millwrights at the mod yard
  - Mod yards aren't familiar with preserving machinery (what to do, why, how, when)
  - We had a few pumps that were going to be oil mist lubricated that were filled with grease, which required the disassembly of the pump to clean out the grease
- Preserving equipment delivered to site proved to be a challenge
  - We did not have a specification outlining what needed to be done, believing that API 686 laid it out pretty well. The problem was that the people responsible for this task in the Contractor org's don't know API 686, and aren't familiar with the equipment on the project (at the beginning anyway)
  - Required a lot of walking through lay-down yards to see what was at site now, checking to see that it was on a list for preservation activities, that those activities were sensible, that they were actually being done, etc
- Afterward we wrote a specification for preservation of equipment that included most of the API 686 content and some simplified tables of activities required



# Vendor Reps

- The issue with Vendor Reps is control and cost
  - During Construction, the cost of vendor reps is with the Unit Project/Construction team, whereas during C&SU the cost of vendor reps is with the Owners OPS team
  - The Unit Project/Construction team did not always take the advice of the Owner Rotating Engineer on which Vendor reps are required, when they are required, and when they are not required (...they should). The OPS team was much more likely to take the advice of the Rotating group.
  - The estimates for vendor reps during construction were vastly exceeded





# Alarm and Trip Settings

- We audited the alarm and trip settings (vibration, bearing temps) for all rotating equipment prior to start-up and found lots of errors and inconsistencies
  - We deleted trips on critical utility equipment like CW Circ pumps, HP BFW pumps (except for turbine overspeed) and added Critical alarms instead (which get immediate Operator attention)
  - We added a trip delay of 2 seconds (except on overspeed and axial position)
  - Implemented a consistent criteria for hydrodynamic thrust bearings: alarm at  $\pm (1/2 \times \text{float} + 15 \text{ mils})$ , trip at  $\pm (\text{alarm} + 5 \text{ mils})$
  - Implemented a consistent criteria for hydrodynamic radial bearings: alarm at 50% of diametral clearance, trip at 75% of diametral clearance (but left the vendor values for gears, Vorecon units)
  - No trips on bearing temperatures or casing vibration
- Trip Multiply settings were inconsistent
  - We implemented a consistent criteria (after reviewing actual start-up data in System 1) of 2x for 10 seconds for 1&2 stage pumps and for 20 seconds for multi-stage pumps



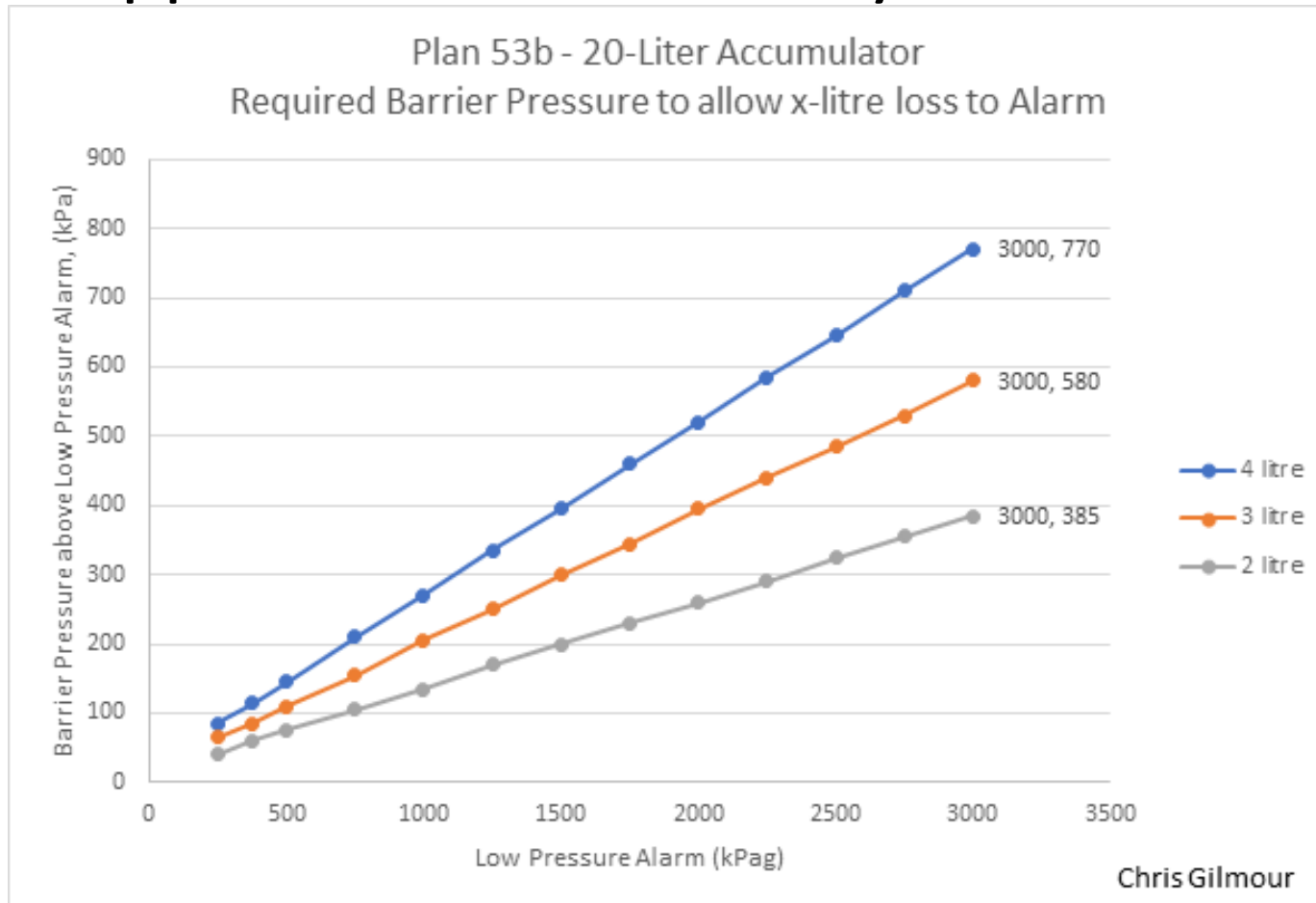
# Seal System Reviews

- We audited the seal systems to ensure
  - Barrier fluid selections were as agreed previously (since this was an Owner responsibility, they left it with whatever we said we wanted)
  - Seal chamber pressures on the seal XS dwgs made sense (most were fine, there were a few that under scrutiny turned out to be incorrect, mostly for 2-stage BB2 pumps)
  - Barrier fluid pressure was sensible (we needed to make a lot of changes here). Generally we set these at the higher of 210 kPa over Normal box pressure or 140 kPa over Max box pressure
  - Alarm points were sensible (we needed to make a lot of changes here). Generally we set these at the higher of 70 kPa over Normal box pressure or 35 kPa over Max box pressure
  - For the Plan 53b's, where we are finding we have to top up too frequently, we are increasing the barrier pressure to increase the interval between top-ups



# Seal System Reviews

- New approach for Plan 53b systems:



# Modularization of Pumps

- We had quite a range of (contractor-driven) approaches to modularization on this project
- One contractor modularized as much as possible, and we had numerous discussions about necessary analyses to ensure no vibration issues (and we did not end up with any), and about the design details necessary for levelling the pumps after setting the modules
- Other contractors seemed to think that modularizing pumps was similar to putting a filter in a module, and did not pay much attention to the design details
- In my opinion, although it is possible to modularize large pumps successfully, I do not see there is any cost/time/quality advantage to doing so for an onshore project in a non-remote location like this project. I do agree that modularizing around the pumps saves cost/time and improves quality.
- Also, the various analyses conducted showed that modularizing OH2 pumps presented fewer dynamic issues than modularizing larger OH3 pumps
- Afterward we revised our installation design requirements to allow the modularization of vertical inline pumps (which we now limit to 100hp), and horizontal pumps up to 200hp, but require the design to incorporate a means to level the pump (we prefer RL Rowan Exactalign adjustable chocks), and proper details around the anchor bolts (gussets, anchor bolt stretch length of at least 10x bolt diameter) ... and of course the pump level and pipe-to-pump alignments need to be demonstrated at the site after setting of the module



# Construction Issues

- We had some units where we never had an opportunity to review the ITP's, and had a running battle to be involved where we wanted
- A surprising number of anchor bolts were cast in the wrong location, requiring them to be cored out and re-positioned
- We observed (and intervened): levelling baseplates w/o removing the driver, welding on pump baseplates, welding on piping attached to pumps, piping being pulled into place with come-alongs, pumps being moved on baseplates to align with piping, trying to use tapered shims and partial shims... pretty much everything you could imagine
  - Our intervention was not always viewed (by the contractor, by the Unit Project/Construction team) in a positive light



# BB5 Pump with Grayloc Hubs

- We had an issue with four carbon-steel BB5 pumps with Grayloc hubs where water entered the barrels and led to corrosion
  - The BB5 pump has the nozzles on top
  - The Grayloc hubs were required for the services with very high pressures
  - The Grayloc hubs do not seal well enough during storage to prevent the ingress of water
  - Lots of theories about how this was due to the pumps not being adequately drained/dried/preserved, but never proven
- Afterwards we changed our pump specification to require the disassembly of BB5 and BB3 pumps after test to ensure they are clean/dry/preserved; also, the simple expedient of putting a bucket over the hubs would prevent water ingress



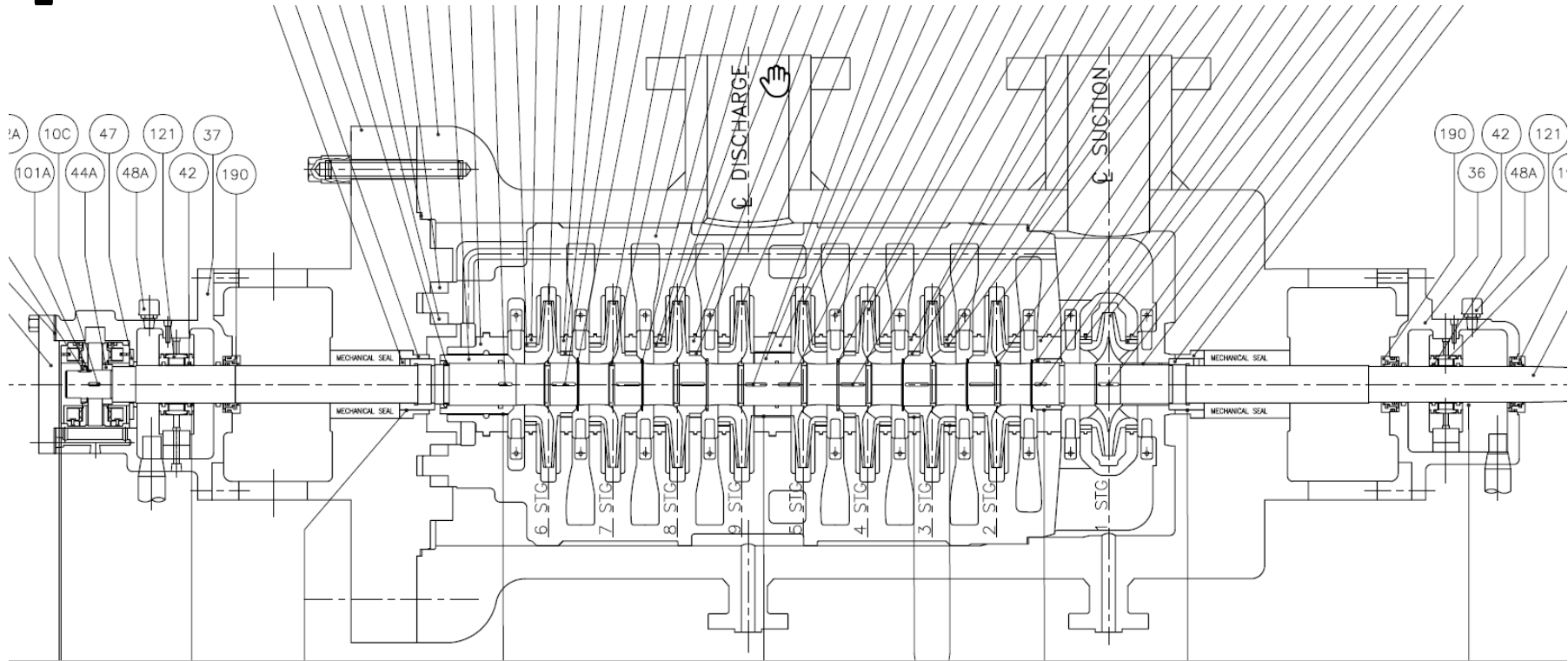
# BB5 Pump with Grayloc Hubs



13-PU103 common spare pump for 13-PU101/102 – final inspection at GE, Italy, Dec-2013



# BB5 Pump with Grayloc Hubs





# BB1 Pump – Axial Shuttling

- We had a couple of issues with a large (10x14x20, 1800rpm, 900hp) BB1 pump service, resulting in seal failure and poor seal life (this service has dual pressurized seals with Plan 53b)
  - OPS started the pump with the suction and discharge valves full open; the Q-rated is 1764 m<sup>3</sup>/hr (7765 gpm); the acceleration of the fluid column as the pump started shook the pump and piping visibly and resulted in the immediate failure of the seals. Procedures were modified to require the discharge valve to be nearly closed on start
  - axial shuttling of the pump was leading to poor seal life; this service had a Q-min system, and increasing the setpoint from the MCSF to the lower bound of the Preferred Operating Range greatly reduced the shuttling
  - To reduce the frequency of topping-up the seal pots, further changes being considered are to increase the barrier fluid pressure and/or to increase the accumulator size (or add another one for each seal, thereby doubling the effective size)



# Seal Flush Coolers – Chloride Issue

- The plant cooling water has high chlorides (up to 1500 ppm), so Chloride Stress Cracking (CSC) of austenitic SS in coolers was a potential issue
- We had specified lube oil cooler tube materials to avoid issues, but had missed the seal flush coolers
- When we realized, most of them had been ordered and were being delivered and were 316SS
- We convinced ourselves it would only be an issue where the CW temperature was 60C or higher; normal CW supply / return temperatures are 25C / 40C; to be safe we decided to change it if the seal barrier fluid temperature would approach 60C, and worked with John Crane to estimate heat loads and thermal performance (fortunately all the hot services with Plan 53b had circulation pumps)
- We ended up identifying services with heat loads above 12,500 BTU/hr (3.6 kW) as potential issues, and replacing the 316SS coils with Duplex SS coils (16 cooler tube sets replaced after delivery)



# Pipe Strain

- All installations at site met the API 686 pipe strain criteria, and were witnessed by the Owner
  - We did have an issue with agreeing on how to measure the pipe strain for vertical inline pumps (the instruction in API 686 is not sensible); we ended up measuring the pump shaft movement from a bracket mounted on the pump soleplate
  - We had an issue with one contractor refusing to do spring-hanger function checks during construction, arguing that this is an activity that should be done after the lines are filled with fluid. It is better to do them during construction, when all the trades are around and the engineering office is available to support, than during commissioning when it is more likely they will be missed. The weight of the fluid in the lines is (typically) less than 20% of the weight being supported (the valves are dominant) anyway.



# Pipe Strain Issue

- We had an issue with pipe strain on a large and hot BB2 pump (10x16x25, 2-stage, 1800rpm, 1500hp, 350C) that showed up as high vibration, sleeve bearing damage, and the pump seizing (while being started; the centre-bushing seized)
- A 3<sup>rd</sup>-party pipe stress analysis showed excessive piping loads, and a revised pipe arrangement has been designed with implementation at the next turnaround
- In the meantime, the centre-bushing clearance was increased, bearing cooling is being added, and higher vibration levels are being tolerated but monitored



# VIL Pumps – 3600rpm bearing issue

- We had an issue with one manufacturer's (not our SOC) VIL pumps running at 3600rpm (there are 7 services, 14 pumps in total)
  - The way the coupling guard was designed there was no way to measure the bearing bracket vibration without removing the coupling guard while the pump was operating; this wasn't considered safe, so the vibration levels weren't being monitored
  - The pump bearings were pure oil mist lubricated, but the bearing bracket had a close-clearance pumping ring in it (a left-over from when the bearings were self-lubed with an oil bath and a pumping ring)
  - Eventually we became aware of vibration issues with all of these pumps operating at 3600rpm (but not a problem for the 1800rpm pumps with the same arrangement), but the pump bearings / shaft / seals were damaged by that point
  - Replacing damaged parts and removing the pumping ring resolved the issue



# Pumps Running out on Curves

- We had a few pumps that were running way out on their curves and cavitating or overloading motors
  - Some are temporary situations until ‘normal’ operating conditions develop
  - Others are due to over-conservative assumptions on hydraulics (generally destination pressures assumed too high)
  - The general mitigation approach was to install a restriction orifice to steepen the hydraulic curve and bring the flow back into the desired range



# VS1 Pumps – seal failures

- We had a few seal failures on VS1 pumps in water service (which all had single seals with plan 13)
  - Some were installed outside, and everything but the seal flush tubing had been heat traced and insulated (so it was frozen; it also needs to be heat traced and insulated)
    - Many of these pumps did not have correct seal flush tubing configurations, and we ended up modifying them
  - Some had ‘cheap + nasty’ discharge check valves which were leaking a lot and causing the pump to spin backwards (better quality check valves are required)



# Oil Mist Systems

- We had some challenges with the oil mist systems
  - Some of the EPC's wanted to model it / spool it / put it in modules
    - Required a lot of effort to review it (and review it again after the layout was changed) to ensure it would work properly
    - It is 2" threaded galvanized pipe, probably would have been cheaper to field install
  - In spite of our spec (and reminders) that the system needed to be kept clean as it was being assembled, some of the systems were very dirty and required a lot of time and effort to get to an acceptable cleanliness prior to start-up
  - We need to add additional heating and insulation to the oil mist generators





# Auxiliary P&ID's

- In my opinion, late development of auxiliary P&ID's was a problem
  - Auxiliary P&ID sketches were developed in early 2012, but in some units weren't drafted until just before IFC, at which time all the instrumentation, utility requirements, electrical wiring, HT&I scope, etc, was a big surprise to everybody else
  - In my view, these should be Issued for Design prior to the 60% Model Review



# Thank You!

- Questions?

